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RESEARCH TRIANGLE INSTITUTE
Durham, North Carolina

FINAL REPORT: VOLUME I, General Considerations
R-OU-156

Radiological Recovery Concepts, Requirements,
and Structures

by

J. T. Ryan, J. D. Douglass, Jr., and H. E. Campbell
October 16, 1964

Prepared for

Office of Civil Defense
United States Department of the Army
under

Office of Civil Defense Contract No. OCD-PS-64-56
OCD Subtask 3233B
RTI Project OU-156

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PREFACE

This is Volume I of two separately bound volumes that report the research completed under the general terms of the Office of Civil Defense Subtask No. 3233B, "Radiological Recovery Concepts, Requirements, and Structures." This volume describes the general aspects of the investigations and presents the conclusions and recommendations. Volume II describes five supporting studies all previously reported to the Office of Civil Defense in research memoranda. The abstract for each of the volumes is presented on the following pages.

The authors are pleased to acknowledge the valuable computer assistance of Mr. Quentin Ludgin of the Research Triangle Institute during the course of the project.

ABSTRACT FOR VOLUME I

This study examines the effectiveness and costs associated with the application of decontamination to accelerating recovery of an activity in a postattack fallout environment. The effectiveness is measured in two ways: first, by the fractional reduction in dose rate that can be achieved by decontamination, and second, when the dose received during the activity is specified, by the fractional reduction in denial time that can be achieved by decontamination. The costs are described in terms of the personnel and equipment required for the decontamination, the radiation doses received by the personnel, and the water required by the operation. The recovery of an activity is defined in terms of radiation doses received by the activity personnel in performing the activity. When these doses are reduced to an acceptable safety level by reducing the dose rate in the activity area, the activity is said to be recovered. The above dose constraints are expressed both in terms of the maximum total dose and in terms of the maximum equivalent residual dose. The primary conclusion reached, that decontamination is as vital to recovery as shelters are to survival in a fallout environment, is the basis for recommending further studies analyzing the application of decontamination to integrated whole-city recovery.

ABSTRACT FOR VOLUME II

Volume II contains five studies concerned with determining the costs and effectiveness of decontamination applied to postattack recovery in a fallout environment. These studies cover the following subjects:

(1) The Effect of Early Decontamination on Total Dose: This study describes the effect of a single (discrete) reduction in radiation intensity (as by decontamination) on an individual's dose history in a $t^{-1.2}$ radiation field;

(2) The Effect of Early Decontamination on ERD: This analysis is like the first in describing the effect of a single reduction in radiation intensity, except that an individual's dose is measured in terms of his ERD;

(3) Total Dose Approximations for Brief Exposure in a Fallout Environment: Two approximations to the expression used to calculate total dose for a finite exposure time in a t^{-k} radiation field are developed and the resultant error is estimated. The approximations are then used to determine the earliest time of entry (for a fixed allowable dose) when a countermeasure operations such as decontamination is employed;

(4) The Effectiveness of Radiological Countermeasures in Accelerating Postattack Recovery: This study develops the parametric relationships that determine the extent to which radiological countermeasures could accelerate the postattack recovery process; e.g., time saved in recovering an activity as a function of the duration of the activity, the time when the activity was to have commenced, the allowable dose received by the activity personnel, the fallout reference intensity, and the effect of decontamination of the intensity.

(5) Studies of Decontamination Effectiveness: This analysis is primarily concerned with the costs and effectiveness of decontamination on and around nine NFSS structures, in reducing the dose rate inside or near the structures.

A parametric analysis of fictitious structures is also included to examine certain parameters (floor and wall weights, story of the detector, number and size of apertures, etc.) in a controlled manner to determine their contribution to dose rate reduction. A similar parametric analysis is made of streets and intersections in an urban area.

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GLOSSARY OF SYMBOLS FOR VOLUME I

D	The dose used to represent the activity dose ($D = R_{NA} D_s$).
D_A	The allowable activity dose (the maximum specified dose while performing the activity).
D_s	Dose received during the performance of the activity where decontamination is not performed prior to the performance of the activity.
d_i	The fraction of fallout uniformly removed from a contaminated plane i .
E_i	The fraction of fallout remaining on contaminated plane i after decontaminating the plane. ($E_i = 1 - d_i$).
F_j	The combined intensity reduction factor - the fraction of the pre-decontamination dose-rate remaining at detector location j after decontaminating several surfaces simultaneously. ($F_j = 1 - R_j$).
F_j^*	The fraction of the pre-decontamination dose rate remaining at detector location j after perfectly decontaminating one or more surfaces upon which fallout is deposited. ($F_j^* = 1 - \sum_i r_{i,j}^*$)
H	The activity intensity ($H = I(1) R_{NA}$) without decontamination.
$I(1)$	The reference unit time dose rate applicable to the region where an activity is located.
$I_s(t)$	The dose rate at a point at time t ($I_s(t) = I(1) t^{-1.2}$ roentgens/hr).
R_j	The fraction of dose-rate removed at detector location j as a result of decontaminating several surfaces simultaneously. ($R_j = \sum_i r_{i,j}$).
R_{NA}	Activity Residual Number - the total radiation dose received during the performance of an activity divided by the total dose that would be received during the same time period in the standard environment.
$r_{i,j}$	The fraction of dose-rate removed at detector location j after decontaminating surface i .
$r_{i,j}^*$	The fraction of dose-rate that would be removed at detector location j after removing all of the fallout material from surface i ($r_{i,j}^* = d_i r_{i,j}$).

T_D

Denial Time - The length of time after fallout arrives that must elapse before an activity can be safely resumed in a fallout contaminated area.

t_e

The time in hours when the activity commences.

Δt

The duration of an activity.

$W(t-x)$

The appropriate weighting function, normally equal to $.1 + .9e^{-.001(t-x)}$ for ERD and equal to 1.0 for total dose.

Chapter 1

Summary and Introduction

I. GOVERNING OCD PROGRAM OBJECTIVE

One of the goals of the postattack decontamination research program of which this subtask is a part, is to provide planners at all levels with the necessary analyses on which to base realistic planning documents, to implement effective training programs, to procure and preposition essential decontamination equipment and material, and to design a system for coordination and control of decontamination measures. This, of course, includes the provision of information for planning guides and manuals for use by operating personnel in the postattack period.

II. FORMAL SUBTASK DESCRIPTION

To partially meet the above broad objectives, the research reported herein was undertaken. This study consists of a general examination of the application of decontamination countermeasures in a postattack nuclear environment. The research undertaken in this subtask is described formally as follows:

"The subject research project will analyze decontamination operations to determine their potential contributions to accelerating recovery in a postattack fallout environment. The primary measure of effectiveness will be the time requirements of alternative recovery options. Recovery here will be interpreted as a return to a specified percentage of pre-attack level of capability, "normal" capacity, or other unit of measure appropriate to the facility or complex of activities. In the beginning, recovery will be measured in terms of the effective labor force numbers and work load capability. At certain times, the dose constraints will limit the work scheduling and effectiveness of personnel. Decontamination can hasten the time at which a particular work schedule can be implemented within the limitations imposed by the dose constraints. Derivation of alternative times, and associated decontamination resource requirements to resume a work schedule, as a function of decontamination effort, is the objective of this subtask."

The above language is a modification of the original contract work statement, suggested by OCD, and recorded in Reference 7. For completeness, the original contract language is reproduced in Enclosure (1) to this volume.

In the course of the research, it was mutually agreed by RTI and OCD that increased emphasis should be placed upon detailed calculation of dose reduction due to decontamination in and around real structures. This necessarily entailed a diminished effort in the less critical research areas. Thus, little or no research was directed toward quantitative analysis of "percentage recovery" nor to the trade-offs among manpower, decontamination resources, and time to resume a work schedule. All the essential elements for making such analyses are, however, included in this report. The accomplishments, conclusions, and recommendations arising from this research are summarized in the remainder of this chapter. The subsequent chapters describe the research in more detail.

III. SUMMARY OF ACCOMPLISHMENTS

To establish the various costs, effectiveness measures and requisite data, decontamination is examined as an operation used to reduce the dose rate in a specified area and, therefore, to decrease the dose or denial time associated with entering a contaminated area. In all cases, the effectiveness of the operation is measured by the fractional reduction that is achieved -- in dose-rate (as reported in Volume II, Appendix E), in dose (as reported in Volume II, Appendices A and B), and in denial time (as reported in Volume II, Appendices C and D). These reductions are analyzed and described as functions of:

- (1) The time when decontamination is carried out;
- (2) The H + 1 hour intensity of the local fallout field;
- (3) The natural radiation protection available due to the physical surroundings;
- (4) The characteristics of the activities to be performed in the decontaminated areas; and
- (5) The efficiency characteristics of the methods and equipment used to decontaminate the area.

The various costs involved in the operation are measured by the manhours of labor, the machine-hours of equipment, the gallons of water expended, the amount of fuel used, and the radiation doses received by the decontamination crew members.

The analysis of operational effectiveness, and costs of decontamination operations is addressed primarily to the development of operational planning guides; to a lesser extent, the analysis considers data requirements for effective operations and command and control systems requirements. The operational planning guides take the forms of:

- (1) Operational points of view and associated rules of thumb that place in perspective the important aspects and parameters that govern the value of the operation;
- (2) Specific analytical approaches and performance curves that provide the necessary background of theory and detailed data.

The first type of planning guide is presented in Volume I "General Considerations," while the second type is presented* in Volume II "Specific Considerations and

* Also, see References 8, 9, and 10, which include additional research and information data developed in the course of this project but not included in Volume II because their essential contents are now contained in portions of the included appendices.

Supporting Documents." The specific planning guides included in Volume II are presented to allow the rapid determination of the following:

- (1) The reductions in total dose and maximum equivalent residual dose received in the early postattack period (first two weeks), that can be achieved by reducing the dose rate during the early postattack period (Appendices A and B);
- (2) The reductions in dose rate that can be achieved with a specified level of effort (manpower and equipment) by decontaminating the accessible contaminated planes on and adjacent to a structure (Appendix E);
- (3) Alternative recovery times for activities and associated decontamination resource equipment as a function of the type of activity, the method of decontamination, and the selected H + 1 dose rate in the area (Appendices C and D).

The operational application of these and other planning guides depends on the availability of data that describe:

- (1) Resource availability (personnel and equipment);
- (2) Area radiation environment information necessary to coordinate the recovery of several activities;
- (3) Activity radiation environment information necessary to plan the recovery of a single activity;
- (4) Activity recovery priorities necessary to allocate limited resources for effective area recovery.

The utility of actual operations in a postattack environment will depend on the capability of a command/control system initially to furnish such data and subsequently to coordinate and schedule the operations. The extent to which the utility depends on command/control capabilities is governed by the

personnel and equipment availability, because the primary function of the command/control system applicable to decontamination is expected to be the allocation of scarce resources to a high demand environment.

In this study, the data and system requirements are examined as they apply to the decontamination of single activities. On the basis of an examination of the recovery of nine real structures (Volume II, Appendix E) believed to be representative, it is concluded that decontamination operations in a fallout environment are potentially as vital to postattack recovery as shelters are to postattack survival. That is,

- (1) Practical decontamination methods can reduce the denial time in most cases by at least a factor of ten. (Denial time is the length of time after fallout arrives that must elapse before an activity can be safely resumed in a fallout contaminated area). In many cases, decontamination can reduce the denial time to the extent necessary to allow the safe recovery of activities at the scheduled time of shelter emergence, H + 2 weeks, assuming the fallout shelter was effective in keeping the radiation dose well below lethal levels.
- (2) Practical decontamination methods can increase the radiation protection associated with an individual inside a structure by at least a factor of five, and can increase the radiation protection associated with an individual outside a structure (in an urban area) by at least a factor of twenty.
- (3) Effective decontamination can be performed without exposing the decontamination crews to dangerous levels of radiation during the operation. In most cases, an activity area can be decontaminated with the crew receiving radiation doses that are less than 10 roentgens per man at H + 1 hour dose rates below 10,000 r/hr. when

decontamination is performed at H + 2 weeks. This holds true for modest crew travel times, but could be greater if travel to and from the operation is substantial.

More specific conclusions and supporting examples are presented in the appendices of Volume II and in Chapters 2, 3, and 4 of this volume.

IV. APPROACH

As a radiological countermeasure, decontamination can be employed to achieve one or more different operational objectives. For example, it may be used to accelerate the re-entry and recovery of a contaminated building or building complex. It may be used to reduce the radiation hazard associated with a continuing operation such as the operation of a communication link. It may be used to reduce the radiation dose associated with a sudden, short duration operation, such as an H + 2 week shelter emergence to obtain additional food and supplies. In each of these applications and others that may arise, decontamination achieves the objective by removing fallout material and thus reducing the radiation intensity in the neighboring space. The degree to which a particular operational objective is achieved, depends, 1) on the time when decontamination is performed and 2) on the effectiveness with which decontamination reduces the intensity. The reduction in intensity, in turn, depends on the amount of fallout material removed from specific contaminated planes as a result of decontaminating those planes, and on the importance of each plane as a contributor to the intensity at the point where the intensity reduction is measured or desired.

The initial task in this research project was to determine how the intensity could be reduced in practical situations by decontaminating any or all of the accessible contaminated planes. The methodology employed and

the examples analyzed are presented in detail in Volume II, Appendix E, and are reported in Chapter 2 of this volume.

The subsequent tasks were to determine the effect of these reductions on operational plans and the associated costs in terms of equipment, manpower, water, and crew dose. The effectiveness was primarily viewed in terms of the reductions in recovery time that were achieved by reducing the intensity in the recovery area. The methodology employed and the examples analyzed are presented in detail in Volume II, Appendices C and D, and are reported in Chapter 3 of this volume.

In accomplishing the above tasks the following restrictions were established with the Office of Civil Defense personnel:

- (1) Direct weapons effects are excluded from the spectrum of attack environments considered;
- (2) Extreme natural environments, such as sustained freezing weather, are excluded from direct study.
- (3) Initially, at least, only the whole body gamma radiation hazard from fallout is considered; Beta burnis and ingestion of radioactive material are excluded.
- (4) New, detailed statistical studies of resources (numbers of sweepers, pumpers, power plants, communication centers, critical medical suppliers, etc.) are not undertaken.

Information upon which the task analyses relied heavily included the USNRDL and Curtiss-Wright reports on decontamination method efficiencies (References 1, 2, 3, 4, and 5) and the OCD Engineering Manual describing the determination of intensity contributions from contaminated planes (Reference 6). In addition, computations of intensity contributions, relied

on an existing computer program, developed at RTI, for protection factor computation.

V. CONCLUSIONS AND RECOMMENDATIONS

The conclusions reached during the course of this study indicate that decontamination is potentially extremely valuable in postattack recovery. These are detailed in the following three chapters of this volume. However, because the conclusions are based on (and extrapolated from) the analyzed recovery of a single activity/facility, it is advisable to validate the significant conclusions in the context of coordinated recovery of metropolitan areas involving many activities/facilities. It is recommended that the studies of realistic situations are reported in Volume II, Appendix E, be extended to satisfy the following objectives:

- (1) Determine the extent--costs and effectiveness-- to which decontamination can accelerate the recovery of large interconnected areas involving the coordinated recovery of many activities essential to the recovery of metropolitan areas.
- (2) Determine the pre-attack and postattack data required for decontaminating metropolitan areas with various levels of effort and/or capability.
- (3) Determine the nature and scope of command and control system elements required for coordinating effective decontamination countermeasures in realistic metropolitan areas.

Chapter 2

The Effect of Decontamination on Dose-Rate Reduction

I. INTRODUCTION

In this chapter the methodology developed to estimate intensity reduction as a function of decontamination effort is reviewed and applied to determine the effectiveness of decontamination as a radiological counter-measure. The methodology employed is developed and discussed extensively in Volume II, Appendix E. In particular, the methodology is applied in an examination of nine representative buildings and the respective intensity reductions that can be achieved by decontaminating on and around the building.

II. A REVIEW OF THE METHODOLOGY AND ANALYSIS

Briefly stated, the radiation intensity at a point is made up of contributions from one or more surfaces upon which fallout material is deposited. These individual contributions to the point radiation intensity from non-overlapping surfaces are linearly and independently related to the overall intensity at a point (See Reference 6). For this reason the effectiveness of decontaminating any single contributing surface can be calculated in terms of reducing the intensity at any of (possibly) several points of interest. For convenience the points of interest are called the detector locations. The individual contributing surfaces are called the contaminated planes. The basic measure of equipment efficiency in terms of fallout removal is simply the fraction of fallout uniformly removed from a given contaminated plane. This fraction of fallout removed is called d_i , where i refers to the

associated contaminated plane. It is specified by USNRDL and Curtiss-Wright (References 1, 2, 3, 4, and 5) as E_i , where $E_i = 1 - d_i$ is the fraction of fallout remaining on the contaminated plane after decontaminating the plane.

Removing a portion of the fallout material deposited on the i^{th} contaminated plane will decrease the radiation intensity at the detector location. After decontaminating a given surface or contaminated plane, a certain fraction of the dose-rate is removed at a specified detector location. The resultant fractional decrease will depend both on the detector location relative to the contaminated plane and on the shielding characteristics of structures in the locality. The fraction that is removed is called $r_{i,j}$, where i designates the i^{th} contaminated plane, and j refers to the specific detector location.

If all of the fallout material is removed from the i^{th} contaminated plane (i.e., $d_i = 1$), then the fraction of dose rate removed at detector location j will be the largest possible value of $r_{i,j}$. We call this fraction removed by perfect decontamination $r_{i,j}^*$, and note the following relation:

$$r_{i,j} = d_i r_{i,j}^*$$

If several planes are decontaminated, then the resultant effect at the detector location is the sum of the individual effects. That is, the fraction of dose-rate removed at detector location j as a result of decontaminating several surfaces simultaneously is:

$$R_j = \sum_i r_{i,j} .$$

If R_j is the fraction of dose rate removed, then $1 - R_j$ is the fraction on the pre-decontamination dose rate remaining. The latter fraction is called the combined intensity reduction factor, F_j , and is defined by the relation

$$F_j = 1 - R_j .$$

Simply stated, F_j is the fraction of the pre-decontamination dose-rate remaining at location j after decontaminating one or more surfaces upon which fallout is deposited. Similarly, we define $F_j^* = 1 - \sum_i r_{i,j}^*$ as the fraction of the pre-decontamination dose-rate remaining after perfectly decontaminating one or more surfaces upon which fallout is deposited.

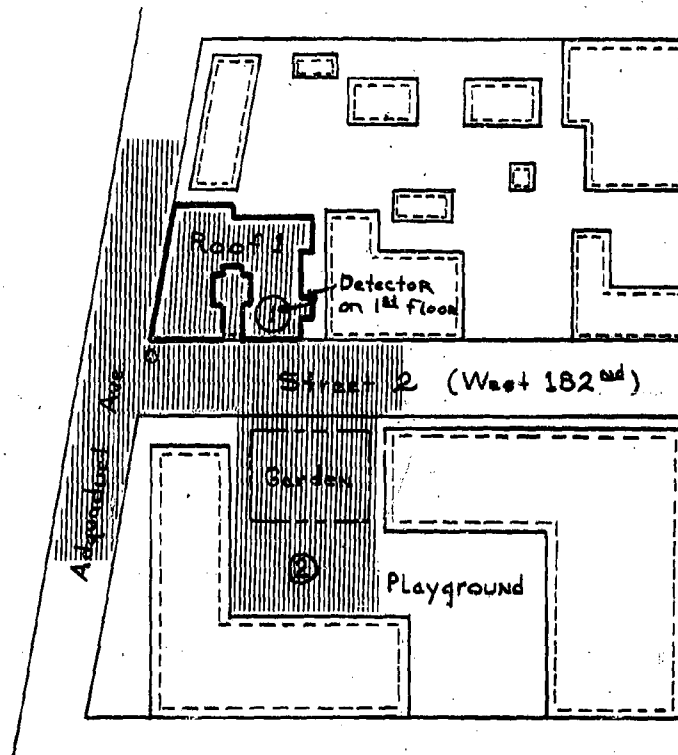
III. AN EXAMPLE ANALYSIS

The manner in which the terms are used to describe the decontamination of a structure will be explained by examining in detail one of the studies contained in Volume II, Appendix E. The study selected is the decontamination of a six-story apartment building located in the Bronx, New York City, and described in Figure 1.

In this example two detector locations are examined. The first detector is located inside the apartment house on the first floor and has associated with it a protection factor of 45; the second detector is located outside the building in the center of the playground of an adjacent school and has associated with it a protection factor of 1.4. To reduce the intensity at these locations the following surfaces were decontaminated:

FIGURE 1

Location Map of Decontamination Areas



● fire hydrants

 principal building

 adjacent buildings

① detector location 1

 Area 1 decontamination area

(1) Roof: 9918 sq. ft. tar and gravel

(2) Ground Level: 15,000 sq. ft. asphaltic concrete on West
182nd Street

16,000 sq. ft. asphaltic concrete on Aqueduct
Avenue

13,000 sq. ft. asphalt on P.S. 91 Playground.

For notational purposes, they were identified as follows:

Area 1 - Roof

Area 2 - Playground

Area 3 - West 182nd Street

Area 4 - Playground, West 182nd Street and Aqueduct Avenue

As a result of decontamination, the following intensity reductions were
calculated:

At detector one (inside on the first floor)

decontaminate roof only (firehose)

with $d_1 = 1$; $r_{1,1}^* = .359$

with $d_1 = .9$; $r_{1,1} = .323$

decontaminate ground surfaces only (street flusher or firehose)

with $d_4 = 1$; $r_{1,4}^* = .506$

with $d_4 = .98$; $r_{1,4} = .496$

From the above, by perfectly decontaminating the roof only, area 1, it is
theoretically possible to remove 35.9% of the dose rate at detector one. By
removing only 90% of the fallout material from the roof, it is possible to
remove 32.3% of the dose rate at detector one. Similarly, by removing 98%
of the fallout material from the ground surfaces, it is possible to remove
49.6% (out of 50.6%) of the intensity at detector one. By decontaminating

both the roof ($d_1 = .9$) and the ground surfaces ($d_4 = .98$) it is possible to remove a total of $32.2 + 49.6 = 81.9\%$ of the dose rate at detector one. In this case the dose rate is reduced to $1 - .819 = .181 = F_1$, or 18.1% of its pre-decontamination value.

At detector two (outside on the playground)

decontaminate playground only (street flusher or firehose)

with $d_2 = 1$; $r_{2,2}^* = .944$

with $d_2 = .99$; $r_{2,2} = .925$

decontaminate West 182nd Street only (street flusher or firehose)

with $d_3 = 1$; $r_{2,3}^* = .037$

with $d_3 = .98$; $r_{2,3} = .036$

From the above, by perfectly decontaminating the playground only, area 2, it is theoretically possible to remove 94.4% of the dose rate at detector two. By removing only 99% of the fallout material from the playground, it is possible to remove 92.5% of the dose rate at detector two. Similarly, by removing 98% of the fallout material from West 182nd Street, it is possible to remove 3.6% (out of 3.7%) of the intensity at detector two. By decontaminating both the playground ($d_2 = .99$) and West 182nd Street ($d_3 = .98$) it is possible to remove a total of $92.5 + 3.6 = 96.1\%$ of the dose rate at detector two. In this case the dose rate is reduced to $1 - .961 = .039 = F_2$ or 3.9% of its pre-decontamination value.

As a result of decontaminating only the ground surfaces -- Area 4 -- the equivalent protection factor associated with detector one becomes $\frac{45}{.5} = 90$ and the equivalent protection factor associated with detector two becomes

$$\frac{1.4}{.039} = 33.$$

Here, it is interesting to notice that before decontaminating, the outside-to-inside intensity ratio was approximately $\frac{45}{1.4} = 32$ and that after decontaminating, the outside-to-inside intensity ratio became approximately $\frac{90}{33} = 2.7$. That is, as a result of decontaminating, the outside-to-inside intensity ratio went from 32 to 2.7. At the same time, the inside equivalent protection factor went from 45 to 90 and the outside equivalent protection factor went from 1.4 to 33.

In bringing about that change, the following costs were calculated:

Roof Decontamination at H + 2 weeks: 7 man team - firehose

d_1 .88 to .99

Team hours required .28 to 1.42

Ground Decontamination at H + 2 weeks: 1 man team - street flusher

d_1 .99

Team hours required .44

This specification is restricted to the actual decontaminating activity and hence does not include such items as:

- (1) Additional crew dose due to the time required to transport people and equipment to and from the site;
- (2) Resources required for the above transportation;
- (3) Requisite coordinating command and control activities such as radiological monitoring; and,
- (4) When appropriate, additional resources required to transport the collected fallout material away from the decontaminated site.

These additional items are not considered here in applying decontamination to a single structure. When several structures are involved, as would be the case in large area recovery involving many structures and activities, these transit considerations must be taken into consideration.

IV. CONCLUSIONS

Based on the analysis of nine buildings believed to be representative structures, it is concluded that decontamination when applied around a single structure can reduce the dose-rate inside the structure by a factor of five (in the preceding example, by a factor of $\frac{1}{.181} = 5.5$) without exposing the crew to a dangerous radiation dose (over 200 r). Furthermore, this decontamination can safely be performed as soon as two days after a detonation where the $H + 1$ reference intensity is less than 1000 r/hr.

The dose-rate outside of the structure can be easily reduced by as much as a factor of twenty (in the preceding example, by a factor of $\frac{1}{.039} = 25.6$) -- again without exposing the crew to a lethal or near lethal radiation dose. Neither the factor of five nor the factor of twenty takes weathering into effect. The effect of weathering is discussed in Volume II, Appendix E.

From the structures analyzed, the fraction of dose-rate removed, R_j , from inside the structure ranged from .48 to .92, with most of the studies showing very close to 85 percent reduction inside the structure. Outside the structure, between 91 and 99 percent of the dose-rate was removed by decontamination.

In the final analysis, it is concluded that, for general planning purposes, at least 90 percent of an individual's daily dose-rate could be removed by decontaminating around the areas (inside and outside) where this person would be spending his time. This amounts to a dose-rate reduction factor of $F_j = .1$. To impart operational significance to this reduction factor, it is necessary to consider its effect on the individual's dose (Volume II, Appendices A and B) or on the recovery denial time when the activity dose is specified in advance. This effect of dose rate reduction on denial time and recovery schedules is the subject of the following chapter.

Chapter 3

The Effect of Dose Rate Reduction on Denial Time

I. INTRODUCTION

In a postattack environment, the initiation or recovery of activities must be scheduled so that radiation dose received by personnel engaged in the activities remains below a safe level. When the radiation dose rate in the region wherein an activity must take place is sufficiently high, the activity cannot take place. In these situations it is necessary to wait until the dose rate decreases to a safe level. The length of time that must elapse before the activity can be recovered is called the denial time T_D . This denial time, T_D , decreases as the dose rate decreases. Therefore, because decontamination can effectively decrease the dose rate in a region, decontamination can effectively decrease the denial time associated with the recovery of an activity. This reduction in denial time is called the time saved in recovering an activity. It will be examined in this chapter as a function of the exposure pattern required in conducting the activity to be recovered, the radiation environment in which the activity is located, the radiation dose history of the personnel engaged in the activity, and the dose rate reduction achieved by decontaminating the activity area.

II. RECOVERY

Recovery is defined as achieving the capability to provide a specified service. As such, recovery depends on the specified service or activity, the personnel who provide the service, and the radiation environment that limits the capability. To isolate the effectiveness of decontamination in postattack

recovery, it is important to distinguish each of the three factors -- activity, personnel, environment -- by its scope and important characteristics.

The specification of an activity is independent of whether the activity is to be performed in a pre-attack or a postattack environment. All activities -- running lathes, manufacturing pills, driving vehicles, operating radio transmitters, clearing debris -- could be performed by (or specified for) fictitious individuals hypothesized to be completely unaffected by radiation.

The specification of an activity includes the complete behavior patterns -- time and location -- of all personnel engaged in the activity throughout the duration of the activity, Δt . A repetition of daily behavior patterns normally will comprise the complete behavior pattern. An activity whose duration is ten days is likely to be a repetition of ten daily activities sufficiently alike to be considered identical. Thus, the activity description includes both working and sleeping patterns. Short duration activities -- less than one day in length -- at the discretion of the analyst can either include or exclude the non-working portion of the day. In discussing an activity, the following discussion refers only to that portion of the day(s) included in the activity specification.

For operations planning, if the established behavior pattern of any individual engaged in the activity is changed, then the activity is changed. This is not meant to imply that the movement of personnel engaged in an activity will not be changed in the planning process to reduce the radiation dose received by the activity personnel. On the contrary, such rescheduling is expected to occur naturally in the planning process. It is merely assumed that any activity that needs to be provided (or recovered) will be done in the

most efficient manner that is possible or practical. Therefore, the invariance attached to activity personnel behavior is attached after the activity has been specified in a manner that minimizes, consistent with the performance of the activity, the dose received by the personnel engaged in the activity. By viewing the activity specification in this manner, it is easy to see that the only way to further reduce the dose received by the activity personnel is to reduce the dose rate in the region wherein the activity is performed.

The personnel engaged in an activity are specified in terms of their individual radiation doses. A dose includes the pre-activity dose, activity dose, and post-activity dose. Together, the three are constrained so that the radiation dose remains below an acceptable safety level. In this study, this safety level is 200 roentgens -- both brief total dose and maximum ERD. When the pre-activity dose and the post-activity dose are analyzed together with the acceptable safety level, it is possible to determine the maximum allowable dose to be received while performing the activity. This dose is called the allowable activity dose, D_A . It may be specified either as a total dose constraint or as an ERD constraint, depending on the duration of the activity. In either case, when coupled with the activity and the environment, it determines the earliest time at which the activity can commence. This earliest time is equal to the time of arrival of the fallout plus the denial time.

When, in addition to the activity, the radiation environment is specified, a dose profile for each individual engaged in the activity can be determined as a function of the time when the activity commences. This dose profile will reflect the various intensity fields through which the individual proceeds

while engaging in the activity. From the dose profile, an individual's dose at any time during and due to the performance of the activity can be determined. The dose received while performing a specified activity will be measured in terms of a standard. The standard is the dose that would be received if the activity were performed at a point three feet above an infinite, smooth, uniformly contaminated plane. The standard dose rate that exists at this point is,

$$I_s(t) = I(1)t^{-1.2} \text{ roentgens/hr.},$$

where t is the time after detonation in hours and $I(1)$ is the reference unit time dose rate applicable to the region where the activity is located. The corresponding dose received during the performance of the activity in the standard environment is, therefore,

$$D_s = I(1) \int_{t_e}^t W(t-x)x^{-1.2} dx \text{ roentgens}$$

where t_e is the time in hours when the activity commences, t is the time of interest in hours, and $W(t-x)$ is the appropriate weighting function, normally equal to $.1 + .9e^{-.001(t-x)}$ for ERD and equal to 1.0 for total dose. The dose used to represent the activity dose is the standard dose multiplied by an appropriate fraction. This fraction, called the activity residual number, R_{NA} , is a constant, independent of the time when the activity commences. The activity residual number is the true total dose received during the performance of the activity divided by the total dose that would be received during the same time period in the standard environment. The function used to represent

the activity dose is, therefore,

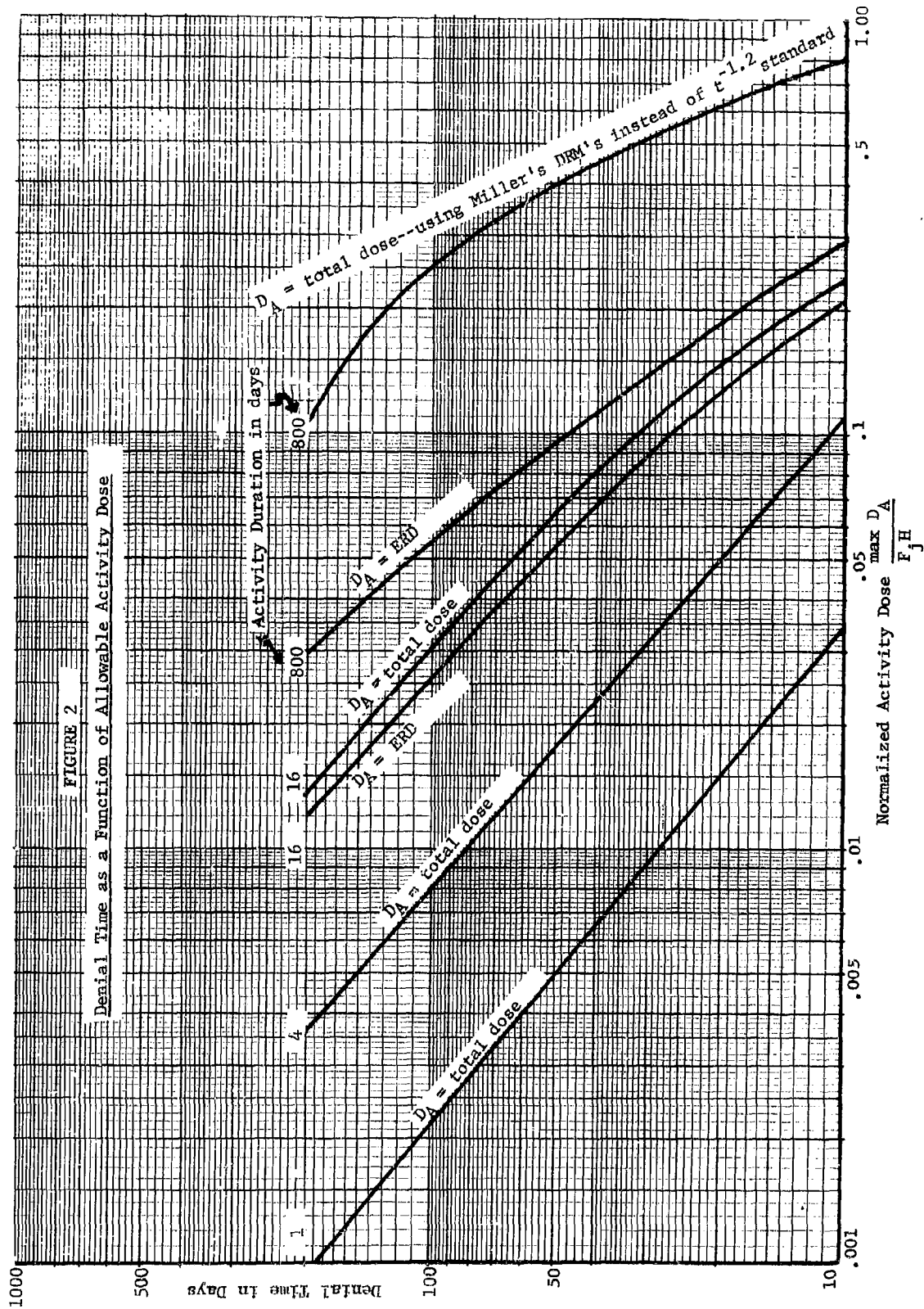
$$\begin{aligned}
 D &= R_{NA} D_s \\
 &= R_{NA} I(1) \int_{t_e}^t W(t-x)x^{-1.2} dx \\
 &= H \int_{t_e}^t W(t-x)x^{-1.2} dx
 \end{aligned}$$

where H is equal to $I(1) R_{NA}$, and is referred to as the activity intensity.

The above representation of the activity dose is used to determine the earliest time of entry when the maximum value of the integral for $t < t_e + \Delta t$ is specified. This maximum value is the allowable activity dose, D_A . When it is specified, along with the environment, and the activity pattern, H, and Δt , then the earliest time at which the activity can commence, t_e , (and therefore, the denial time) can be determined.

III. DENIAL TIME

As previously defined, the denial time is the length of time after detonation that must elapse before an activity can commence. This denial time is shown in Figure 2 as a function the maximum allowable activity dose (total dose and ERD) normalized with respect to H for various activity durations. This figure corresponds to Figure D-9 in Volume II, Appendix D. The total dose curve for an activity duration of 800 days uses Miller's dose rate multipliers (Reference 3) to define the standard dose rate, rather than $I(1)t^{-1.2}$, which is used in constructing all the other curves. The ERD curve for an indefinite activity duration (800 days) was determined graphically.



The ERD curves for activity durations, Δt , less than 32 days were determined from the equation, *

$$t_e = \left(\frac{H \Delta t}{D_A} \right)^{.833} (1 - .008 \Delta t)^{.833} - \frac{\Delta t}{2}$$

and the total dose curves for activity durations less than 32 days were determined from the equation, *

$$t_e = \left(\frac{H \Delta t}{D_A} \right)^{.833} - \frac{\Delta t}{2}$$

IV. DOSE RATE REDUCTION EFFECTIVENESS

If the magnitude of the dose rate is reduced, then the denial time is also reduced. The time by which the denial time is reduced is called the time saved. This time saved, or denial time reduction, is viewed as a measure of the effectiveness of decontamination in assisting recovery in a postattack environment.

When a set of contaminated surfaces in the region where the activity takes place is decontaminated, the activity dose

$$H \int_{t_e}^t W(t-x)x^{-1.2} dx$$

is reduced to

$$F_j H \int_{t_e}^t W(t-x)x^{-1.2} dx$$

where F_j is the fractional reduction in dose rate brought about by the decontamination operation. As discussed in the previous chapter, F_j is expected to range between .05 and .2. In the above equations, the effect of F_j can be interpreted as decreasing the magnitude of the activity dose rate

* See Volume II, Appendix D, equations D-16 and D-17.

from H to F_j times H . Because F_j is less than 1, this is always a decrease. In Figure 2, a decrease in H increases the normalized allowable activity dose, $\frac{D_A}{H}$. When the normalized allowable activity dose increases, the denial time decreases and recovery time is saved.

V. RECOVERY TIME SAVED

From equations and/or curves that relate the denial time to the maximum allowable activity dose, D_A , and the radiation environment activity constant, H , such as are illustrated in the previous section, the actual time saved can be calculated for any set of conditions. This is done in detail in Volume II, Appendix D. For general planning purposes, where extreme detail is neither necessary nor desirable, very simple estimates of the potential time savings attributable to decontamination can be formed by a quick examination of Figure 2. This will be done by determining for various activity durations the fractional reduction in denial time that results when H is decreased by a factor of 10 (that is, when the dose rate reduction achieved by decontamination is $F_j = .1$). The results of such an examination of Figure 2 are presented in Table I. There it can be seen that by reducing the dose rate by a factor of 10, the denial time is reduced by a factor ranging from 7 to 20. For example, if the activity duration is 16 days, the allowable dose (maximum ERD) is 100 roentgens, and $H = I(1) R_{NA} = 5000$ roentgens per hour, then the denial time is 130 days. With a dose rate reduction factor of .1, H becomes 500 roentgens per hour and the denial time is reduced by a factor of 12 to $\frac{130}{12} = 11$ days. This example is presented as a portion of Table I.

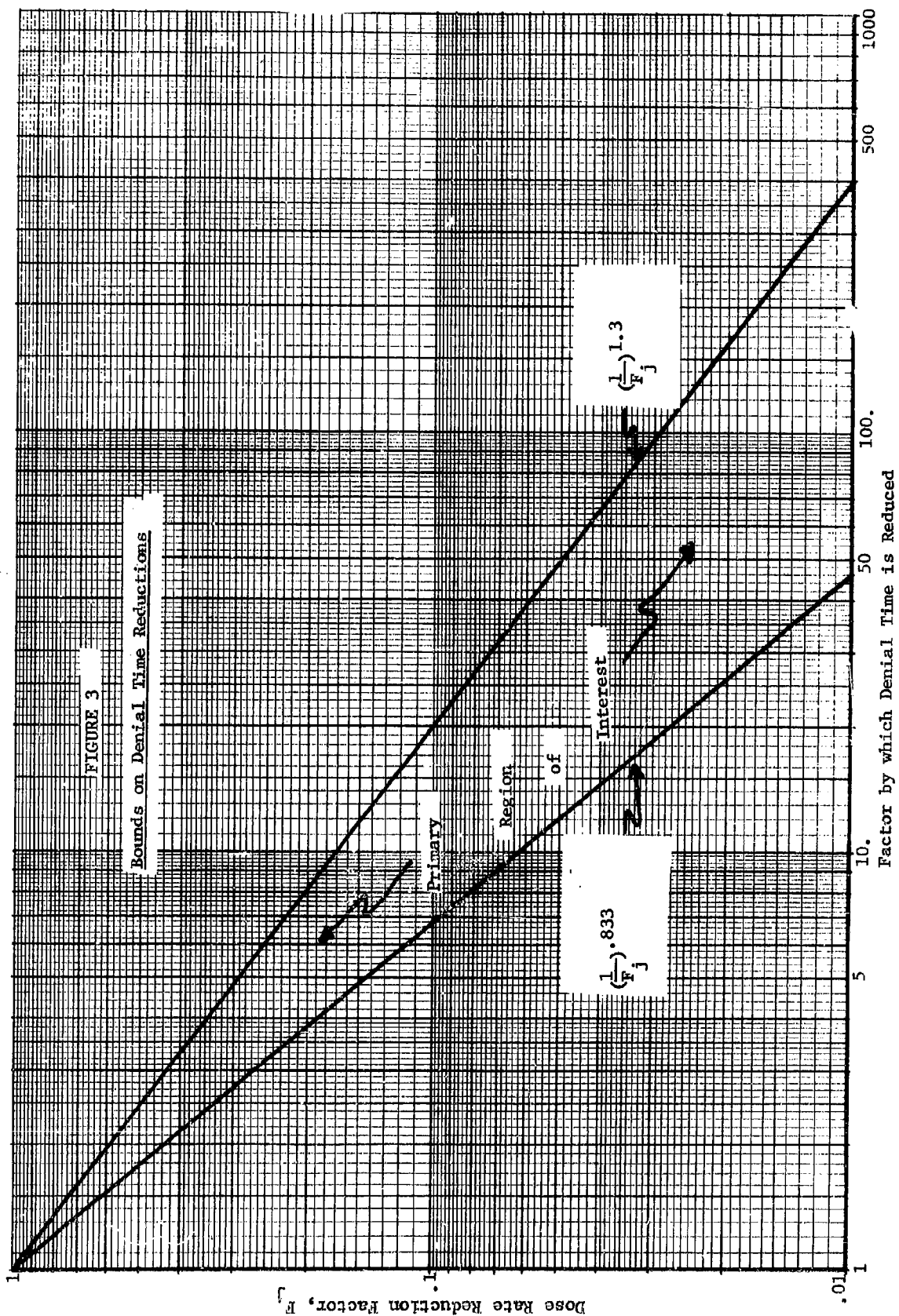


TABLE I

Examples of the Effect of $F_j = .1$ on Denial Time

Activity Duration	Criterion	$\frac{DA}{H}$	Denial Time	Dose Rate Reduction	Denial Time Reduction
800 days (indefinitely)	ERD	$\frac{100 \text{ r}}{350 \text{ r/hr.}}$ or $\frac{200 \text{ r}}{700 \text{ r/hr.}}$	10 days	$F_j = 1/10$	1/20
		$\frac{100 \text{ r}}{3,500 \text{ r/hr.}}$ or $\frac{200 \text{ r}}{7,000 \text{ r/hr.}}$	200 days		
16 days	ERD	$\frac{100 \text{ r}}{500 \text{ r/hr.}}$ or $\frac{200 \text{ r}}{1,000 \text{ r/hr.}}$	11 days	$F_j = 1/10$	1/12
		$\frac{100 \text{ r}}{5,000 \text{ r/hr.}}$ or $\frac{200 \text{ r}}{10,000 \text{ r/hr.}}$	130 days		
16 days	Total Dose	$\frac{100 \text{ r}}{500 \text{ r/hr.}}$ or $\frac{200 \text{ r}}{1,000 \text{ r/hr.}}$	131 days	$F_j = 1/10$	1/11
		$\frac{100 \text{ r}}{5,000 \text{ r/hr.}}$ or $\frac{200 \text{ r}}{10,000 \text{ r/hr.}}$	143 days		
4 days	Total Dose	$\frac{100 \text{ r}}{1,000 \text{ r/hr.}}$ or $\frac{200 \text{ r}}{2,000 \text{ r/hr.}}$	11 days	$F_j = 1/10$	1/7.6
		$\frac{100 \text{ r}}{10,000 \text{ r/hr.}}$ or $\frac{200 \text{ r}}{20,000 \text{ r/hr.}}$	84 days		

For rough planning purposes it is often desirable to have available methods of estimating the range of decontamination effectiveness. As a general rule, if the dose rate reduction factor is F_j , then the denial time will be reduced by dividing it by a factor that is greater than $(\frac{1}{F_j})^{.833}$ and less than $(\frac{1}{F_j})^{1.3}$. Referring to the previous example, $(10)^{.833} = 6.8 \approx 7$ and $(10)^{1.3} = 20$. These two bounds, indicating the range of factors by which the denial time is divided as a result of decontaminating the activity area, are shown in Figure 3. The actual value for the factor is a function of D_A , H , F and can be determined using the performance curves presented in Volume II, Appendix D.

VI. CONCLUSIONS

The situations examined in Chapter 2 indicate that decontamination methods should be able to provide dose rate reductions in the vicinity of $F_j = .1$ and that such reductions would entail crew radiation doses of less than 10 r/hour of decontamination activity when the initial $H + 1$ intensity, $I(1)$, is below 10,000 r/hr and when decontamination is activated at time $H + 2$ weeks or later. From the material presented in the present chapter, it can be seen that for an $F_j = .1$, the denial time for a one-day activity can be reduced to less than 15 days whenever the ratio $\frac{D_A}{F_j H}$ is greater than .25 and therefore whenever the ratio $\frac{D_A}{H}$ is greater than .025. Here D_A is considered a maximum ERD for activity durations greater than 30 days and either a maximum ERD or a maximum total dose for activity durations less than or equal to 30 days. Therefore, if maximum ERD is the constrained dose, D_A , and $F_j = .1$, then the denial time for any duration activity can be reduced

to 15 days, provided D_A is greater than $.025H$. For example, if D_A is 50r, then H must be less than 2000 r/hr. Because H is $I(1)$ times the activity residual number, if the activity residual number is $\frac{1}{15} = .0667$, then the corresponding constraint on the initial $H + 1$ intensity is that $I(1)$ be less than $15 \times 2000 = 30,000$ r/hr. This type of information is summarized in Table II for $F_j = .2, .1, \text{ and } .05$. It should be noted that the H intensity includes the protection given the individual by the facilities in which the activities are performed, but not the effect of decontamination.

TABLE II

Decontamination Effectiveness When the Maximum
Allowable Activity Dose is Limited to 100 Roentgens

Dose Rate Reduction F_j	Activity Duration Δt	Activity Intensity* at H+1 hr.		Denial Time Without Decontamination	Denial Time With F_j Decontamination
.2	$\Delta t > 30$ days	10,000 r/hr	over	300 days	100 days
		3,000 r/hr		170 days	24 days
		1,000 r/hr		47 days	under 10 days**
	$\Delta t < 16$ days	10,000 r/hr		220 days	68 days
		3,000 r/hr		83 days	15 days
		1,000 r/hr		28 days	under 10 days
.1	$\Delta t > 30$ days	10,000 r/hr	over	300 days	47 days
		3,000 r/hr		170 days	10 days
		1,000 r/hr		47 days	under 10 days
	$\Delta t < 16$ days	10,000 r/hr		220 days	28 days
		3,000 r/hr		83 days	under 10 days
		1,000 r/hr		28 days	under 10 days
.05	$\Delta t > 30$ days	10,000 r/hr	over	300 days	18 days
		3,000 r/hr		170 days	under 10 days
		1,000 r/hr		47 days	under 10 days
	$\Delta t < 16$ days	10,000 r/hr		220 days	11 days
		3,000 r/hr		83 days	under 10 days
		1,000 r/hr		28 days	under 10 days

* This intensity is equal to $I(1)R_{NA}$ and therefore includes any protection (R_{NA}) afforded the individual by the facility in which the activity takes place. The corresponding standard H + 1 intensity, $I(1)$, will be considerably larger than the activity intensities.

** "Under 10 days" is used to emphasize that these reductions are less than scheduled shelter emergence, H + 14 days. The actual denial time can be determined, if desired, from the performance curves presented in Volume II, Appendix D.

Chapter 4

Conclusions and Recommendations

I. INTRODUCTION

In a moderate to severe postattack fallout environment great care must be exercised to ensure that individual radiation doses remain below an acceptable safety level. In accomplishing this objective, fallout shelters are the first most important single implement. They pave the way for recovery by protecting the population in the early fallout environment. When shelter emergence becomes possible, however, more direct actions toward recovery are not only warranted, but, in fact, are absolutely essential. Areas and facilities other than shelters must be made habitable in the same sense that shelters are habitable -- they must be made to protect the occupants from radiation exposure damage.

It is in such broad recovery problems, beginning with shelter emergence, that decontamination is as vital to recovery as shelters were to survival. The self-recovery of such areas and facilities that occurs as a natural consequence of radioactive decay will proceed at this time, in many cases, too slowly to provide the necessary hospitals, pharmaceuticals, food, water, and sanitation facilities, not to mention manufacturing, recreation and morale activities. It requires fourteen weeks for the same decay (partial recovery) to occur beginning at $H + 2$ weeks that previously took 7 hours beginning at $H + 1$ hour. Decontamination makes practicable the quick recovery of areas and facilities while simultaneously limiting individual radiation dose levels to an acceptable range.

In analyzing the costs and contributions of decontamination, recovery operations were modeled to conform with the actual situation that might exist in the postattack environment. Whenever possible, emphasis was placed on that

information predicted to be most available and valuable in the postattack recovery phase. Thus, dose constraints on all operating personnel were carried throughout the analyses as independent variables. Monitoring information concerning intensity levels was also carried throughout the analyses as an independent variable. In terms of these two variables and specific facility/activity protection factor information, which can be either calculated in advance or measured on the spot, the performance characteristics (costs and effectiveness) of decontamination were determined and analyzed, yielding the following conclusions and recommendations.

II. CONCLUSIONS

The major conclusions derived from the analyses performed are:

- (1) Decontamination can be an effective means for accelerating recovery in a postattack radiological environment. Denial time can be reduced in most cases by a factor of 10. In addition, denial time can be reduced in most cases to less than the scheduled time of shelter emergence, 2 weeks.
- (2) Decontamination can reduce dose-rates inside structures by a factor of 5 and outside such structures (in built up urban areas) by a factor of 20.
- (3) An activity area generally can be decontaminated without exposing the crews to lethal doses, and, in many cases, this decontamination can be accomplished with the crew receiving doses of less than 10 roentgens per man at an initial intensity of 10,000 r/hr when decontamination is accomplished at H + 2 weeks.

- (4) When estimating reduced denial time for an activity or facility as a function of decontamination, the equipment effectiveness is (in terms of mass particle removal) not critical within the ranges considered.

III. RECOMMENDATIONS FOR FUTURE WORK

Finally, on the basis of these conclusions, it is felt that studies should be extended to embrace the following aspects:

- (1) Determine the extent to which decontamination can aid the recovery of multi-structure complexes under various fallout environments.
- (2) Determine the cost and effectiveness of decontamination in recovering large city areas.
- (3) Determine the pre-attack and postattack data required for decontaminating city areas with various levels of effort and/or capability.
- (4) Determine the nature and scope of command and control system elements required for conducting effective decontamination countermeasures in practical situations.

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Enclosure (1)

Contract Work Statement, OCD Subtask 3233B,

Radiological Recovery Concepts, Requirements, and Structures

"For a broad spectrum of fallout conditions likely to be encountered in an early postattack nuclear environment develop operational planning guides for effecting decontamination countermeasures which are in conformance with current Office of Civil Defense doctrine and objectives and which are compatible with other radiological countermeasures which may be effected simultaneously or in phase; determine the data prerequisite to effecting decontamination countermeasures for different levels of effort and/or capability; and determine the nature and scope of a command and control system required for conducting effective decontamination countermeasures."

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Radiochemical Recovery Concepts, Requirements and Structures. Joseph T. Ryan et al.
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This is Volume 1 of two volumes which contain the analysis and conclusions reached under OCD Sub-task 32338, Radiochemical Recovery Concepts, Requirements and Structures. This study examines the effectiveness and costs associated with the application of decontamination to accelerating recovery of an activity in a postattack fallout environment. The effectiveness is measured in two ways: first, by the fractional reduction in dose rate that can be achieved by decontamination, and second, when the dose received during the activity is specified, by the fractional reduction in denial time that can be achieved by decontamination. The costs are described in terms of the personnel and equipment required for the decontamination, the radiation doses received by the personnel, and the water required by the operation. The recovery of an activity is defined in terms of radiation doses received by the activity personnel in performing the activity. When these doses are reduced to an acceptable safety level by reducing the dose rate in the activity area, the activity is said to be recovered. The above dose constraints are expressed both in terms of the maximum total dose and in terms of the maximum equivalent residual dose. The primary conclusion reached, that decontamination is as vital to recovery as shelters are to survival in a fallout environment, is the basis for recommending further studies analyzing the application of decontamination to integrated whole-city recovery.

CIVIL DEFENSE, DECONTAMINATION, RECOVERY, RADIOACTIVE FALLOUT, POSTATTACK OPERATIONS, CONTAMINATION, RADIOLOGICAL CONTAMINATION, RADIATION HAZARDS, DOSE RATE, CLEANING, STRUCTURES, PROTECTION FACTOR, CIVIL DEFENSE SYSTEMS.

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